



[Reprinted from PAPERS OF THE MICHIGAN ACADEMY OF SCIENCE, ARTS AND LETTERS, Vol. XXI, 1935. Published 1936]

A MORPHOLOGICAL STUDY OF THE RESPIRATORY SYSTEM IN VARIOUS LARVAL INSTARS OF *STENELMIS SULCATUS* BLATCHLEY (DRYOPIDAE; COLEOPTERA) *

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STENELMIS SULCATUS was described by Blatchley (1910) from specimens found in Lake Maxinkukee, Marshall County, Indiana. This insect is unusual in two respects, namely, type of habitat and possession of certain uncommon morphological structures in the larval stage. The few records so far made for it suggest that it is probably restricted to marl lakes, in which it passes its life, seldom, if ever, coming to the surface for air. Larvae and adults occur in the interstices of marl concretions which, in rare instances, abound in such lakes, or in the common accumulations of marl on shells of mussels or other objects. The insect is well adapted for life in such a situation because of its strong negative reaction to light and its positive thigmotaxis. At the same time, practically buried as it is in the marl accumulations, it is closely associated with the numerous Algae, some of which build the concretions and give off oxygen in their photosynthetic activities. Its morphological interest is presented by the larval stage, which possesses an uncommon set of structures. These are limited to a relatively small group of insects, namely, those of the families Parnidae and Dryopidae, and are sometimes referred to as "caudal gills." In *Stenelmis sulcatus* they consist of three tufts of filaments at the posterior end of the body which are protrusible through the tip of the last abdominal segment. Under certain conditions, such as abnormal increase in temperature of water, exposure to light, high carbon dioxide tension, or low oxygen tension, the larvae rhythmically extend and retract these caudal filaments. Sometimes the rhythm is rapid, sometimes slow, depending upon the conditions to which the larvae are subjected. If, however, several larvae are allowed to rest in a dish of water, they curl up together into a mass,

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1435

and their caudal filaments remain retracted as long as the larvae are left undisturbed. During this quiescent period the larvae are carrying on respiration, apparently without the aid of the caudal filaments. When larvae are subjected to abnormal conditions, the retraction and the extension of the filaments appear, in a measure, to be a response to an irritability which results in a rapid locomotion, and the filaments and the posterior part of the abdomen are used in a way that suggests the rapid backward locomotion of a crayfish. This response is most pronounced when the larvae are submerged in acid, alcohol, warm water, or other medium which makes them extremely uncomfortable. Abnormal carbon dioxide or oxygen tensions do not bring forth so active a response.

Since the most unusual features of *Stenelmis sulcatus* are presented by the larva, only that stage was studied during this investigation. A comparison was made of the morphology and physiology of the respiratory system in three larval instars. The problems that first presented themselves were: (1) Are the larvae catching and using oxygen directly as it is given off by the marl-forming Algae or do they use the dissolved oxygen of the surrounding water? (2) Is the respiratory system an open or a closed one? (3) Do the caudal filaments have a respiratory function?

ACKNOWLEDGMENTS

The writer wishes to express her indebtedness to Professor Paul S. Welch, who guided this investigation; to Mr. Marion R. Raymond, who brought in materials from the field during two winters; and to various other persons who gave valuable advice and assistance.

METHODS

The uninterrupted progress of this investigation over a period of two years was facilitated by the presence of a rich bed of marl concretions in Bass Lake, eighteen miles northwest of Ann Arbor, Michigan. These concretions, containing all stages of the insect except the pupa, can be obtained throughout the year.

CULTURE

Marl concretions from Bass Lake commonly contain life-history stages of *Stenelmis sulcatus*. Sometimes as many as one hundred

larvae of various instars may be found in a medium-sized concretion. Laboratory culture is relatively simple. Concretions may be kept for weeks in an aquarium filled with constantly aerated water at ordinary room temperatures and in a room to which sunlight is admitted for maintenance of the Algae. One culture was maintained for a year under these simple conditions, and during that time all larval instars as well as adults were present. Therefore, eggs are apparently laid throughout the year under these conditions, although attempts to find them among the marl particles were unsuccessful.

TECHNIC

Dissecting Instruments

Stenelmis sulcatus is about 1 mm. in length in its first larval instar and about 5.5 mm. in its last larval instar. It was necessary, therefore, to devise instruments small enough for microscopic dissection.

Gross dissections of the larger larvae were made under the 40-mm. objective of the compound microscope by means of small pieces of a safety razor blade attached to mechanical fingers clamped to the microscope stage. For more delicate dissections fine scalpels were constructed by grinding the points of steel sewing needles to a sharp cutting edge and fitting them into handles.

All dissections were made by partly filling the cavity of a depression slide with paraffin. The larva was held in place in this paraffin by means of one insect "minuten" pin, since the extremely small size of the larva made it impossible to fasten it down at more than one point at a time. The free portion was carefully dissected by using both hands, each supplied with a fine scalpel, or by the use of mechanical fingers.

Phenol Preparations

The efficacy of phenol as a clearing agent suggested its use in a preliminary examination of the larvae before dissection was begun. When living first-instar larvae, which are not so heavily chitinized as the older ones, are placed in phenol, the main tracheal trunks and some of the smaller tracheae are easily visible through the body wall. Therefore, phenol was used in studying the gross aspects of the tracheal system of the first larval instar and in clearing tissues surrounding a given structure. It was especially useful in observing the structure of spiracles and spiracular vestibules.

Glycerine Preparations

Wahl (1900) found glycerine useful in his study of the respiratory system of *Eristalis tenax* L. In accordance with this suggestion, living larvae were submerged in glycerine until the tissues were completely permeated with it. Upon dissection the tracheae appeared silvery white in their glycerine bath, owing to the gas which remained imprisoned within them. This proved an invaluable method for the study of larger tracheal tubes in the older larvae.

Stained Oil Preparations

To study the minute branches and tracheoles, a third method was required. It was found that, when living larvae are submerged in kerosene, xylol, or benzol, these liquids gradually fill the tracheae, rendering them translucent, but that, if these liquids are first stained with Sudan III, the tracheae become colored a decided pink due, according to Hacker (1925), to the adherence of the Sudan III to their walls, so that even the tracheoles are readily visible with the highest magnification of the compound microscope. Staining of the oils was done according to Hacker's method by shaking a slight excess of Sudan III into the liquid and gently heating it. Benzol was the most effective, and only a small quantity was prepared at a time; fresh solutions were made as needed.

MORPHOLOGY OF RESPIRATORY SYSTEM

FIRST LARVAL INSTAR

*Ventral Aspect**Main tracheal trunks*

The main tracheal trunks, seen from the ventral surface (Pl. LXVII, Fig. 1 *mtt*), consist of a pair of large lateral tubes, which gradually become smaller in diameter at the anterior end and, on entering the head (*ht*), divide into numerous branches, which supply the head capsule and the organs within it. At the posterior end and in the region of the last abdominal segment each trunk is divided into two branches, the most lateral of which (*mdt*) extends posteriorly for a short distance, then bends mesad to form an ascending loop, which extends into the body, coming to lie dorsad to the intestine, where it bends once more to form a short descending loop. Here it meets the descending loop from the opposite trunk, and together they supply

the middorsal tuft of the caudal filaments. The second and innermost branch of the main trunk (*lt*) extends posteriorly as a single tube at first, finally dividing into two branches, which remain separated except at the tip, where they approximate to supply the lateral tuft of caudal filaments. Thus each tuft is supplied by two branches of the main tracheal trunks.

Caudal filaments

The caudal filaments appear to be evaginations from the main tracheal trunks, at the posterior ends of which they form, in all, three tufts (Pl. LXVII, Fig. 1 *lt mdt*). The middorsal tuft is the largest and lies dorsad to the intestine. It consists of 47–72 filaments, average 55. The lateral tufts lie ventrad to, and at either side of, the intestine and consist of 24–49 filaments, average 35. The wall of the filament appears to consist of a relatively thick chitinous outer layer and an inner, basement membrane. In the first instar the filaments vary in length from 102 to 151 μ inclusive and have a diameter of 4.8 μ at the proximal end and 2.3 μ at the tip. Each is supplied with two tracheoles from the main trunk which twist spirally around each other and end blindly at the tip.

Transverse connectives

Transverse connectives (Pl. LXVII, Fig. 1 *tc*) extend from one main, longitudinal trunk to the other on the ventral side and, though there are always nine in the first larval instar, the number of branches given off by them to other structures varies somewhat. In one larva a connective in the region of the second abdominal segment gives off two branches to the ganglion in that region, whereas in another larva of the same instar the connective in the same region has three or four branches.

Ganglionic and nerve-cord tracheae

The ganglionic tracheae (Pl. LXVII, Fig. 1 *tns*) are given off by the transverse connectives sometimes from their upper and sometimes from their lower side in the midventral region. Two to four ganglionic tracheae develop from each transverse connective and they, in turn, give off one to three smaller branches to the nerve cord.

Ventral body-wall tracheae

Ventral body-wall tracheae (Pl. LXVII, Fig. 1 *vbw*) are given off from the two main trunks throughout their entire length. These tracheae are not bilaterally symmetrical. In one larva the left trunk may supply a greater number than the right trunk, whereas in another larva the reverse is true. However, all these branches send off tracheoles into the ventral body wall, where the latter anastomose and form a network which supplies the entire ventral side.

Leg tracheae

Tracheae to the legs are likewise supplied by the main tracheal trunks (Pl. LXVII, Fig. 1 *l₁ l₂ l₄*). Here again there is a variation in the number of branches. The first pair, being the largest, is supplied with more branches than are the others. However, the number of branches sent off to the legs on the right side does not always agree with the number sent off to those on the left.

Head tracheae

In the previous discussion of the morphology of the main tracheal trunks it was pointed out that at their anterior ends they send off numerous branches to the head. A ventral view reveals only the branches to the head capsule and to the mouth parts. These branches are variable in number, but are quite simple and need no description. The remainder of the head tracheation is discussed below.

*Dorsal Aspect**Main tracheal trunks*

From a dorsal view (Pl. LXVII, Fig. 2) the main trunks present the same picture as that on the ventral side, except that the dorsal side, having no transverse connectives, reveals the small ectal protrusions (Pl. LXVII, Fig. 2 *ep*) which represent the beginnings of evaginations, from which in older instars the spiracular tracheae develop.

Visceral tracheae

The visceral tracheae are given off from the dorsomesal side of each of the main trunks, forming pairs which are more or less bilaterally symmetrical. In the head region the first two pairs are relatively thick tubes (Pl. LXVII, Fig. 2 *vt₁ vt₂*), which break up into smaller

branches on entering the alimentary tract. A third pair (vt_3) given off farther down, just at the beginning of the prothorax, also sends off smaller branches into the wall of the alimentary tract. The fourth pair (vt_4) takes its origin in the region of the second abdominal segment and, proceeding anteriorly, sends off branches to the intestine, finally breaking up into from five to seven branches, all entering the "gastric mill" located in the prothorax. The fifth pair (vt_5) takes its origin in the region of the third abdominal segment, extending cephalad to supply that portion of the alimentary tract in the first and second abdominal segments. The sixth pair (vt_6) is the most complex. Taking its origin from the main trunks in the region of the fifth abdominal segment, each component of the pair, after a short mesad course, divides into two branches, one of which goes cephalad, sending off smaller branches which supply that part of the intestine located in the third and fourth abdominal segments and branches which supply other visceral organs in the same region, whereas, the second branch extends caudad, also breaking up into smaller branches which supply the portion of intestine in the sixth abdominal segment. Each component of the seventh pair (vt_7), taking its origin in the region of the eighth abdominal segment, likewise divides into two branches, one of which goes cephalad to supply the intestine in the seventh segment and the other caudad to supply the intestine in the region of the eighth and ninth segments.

In the first larval instar the paired visceral tracheae always number seven and always take their origin from the same region of the main trunks. However, the number of smaller branches which they give off to the wall of the digestive tube or of other visceral organs varies a little in larvae of the same instar.

Dorsal body-wall tracheae

Dorsal body-wall tracheae arise from the main tracheal trunks on their lateral faces and are similar in form to those previously described which supply the ventral body wall.

Ocellar tracheae

Ocellar tracheae (Pl. LXVII, Fig. 2 *ot*) arise from one of the branches of the main trunks which supply the head. At its distal end the branch divides into several smaller branches which, in turn, resemble the recurved fingers of a hand. These curved, finger-like

tracheae terminate in the region of the ocelli, and there are never fewer than four and never more than five in each group. They are usually bilaterally symmetrical, the number being the same for both groups of ocelli in the same larva.

Antennal tracheae

Antennal tracheae (Pl. LXVII, Fig. 2 *at*) are likewise given off from one of the branches of the main tracheal trunks supplying the head. Usually two, and sometimes three, tracheae supply each antenna; these are quite simple and need no further description.

MORPHOLOGY OF AN INTERMEDIATE LARVAL INSTAR

The intermediate larval instar here described is, in all probability, the third instar although, owing to the rather unsatisfactory results of breeding experiments, the writer does not wish to state definitely that it is the third. Consequently the instar studied throughout this investigation will be referred to as an intermediate larval instar. The larva in question is about 3 mm. long and shows a stage of development midway between that of the first instar and that of the last.

Ventral Aspect

Main tracheal trunks

In this instar each main tracheal trunk (Pl. LXVIII, Figs. 1-2) possesses a definite form having a well-defined ental bend between each two of the developing spiracular tracheae. At their anterior and posterior ends no further developmental changes occur in the main trunks except for a more regular curvature of the branches leading to the caudal tufts. Also, the trunks throughout their entire length have a greater diameter than those in the first instar. The evaginations of the spiracular tracheae (Pl. LXVIII, Fig. 1 *ste*) which, in the first instar, were irregular ectal protrusions (Pl. LXVII, Fig. 2 *ep*), now take on a definite form and position; two pairs of them are always present in the thorax and eight pairs in the abdomen.

Spiracular tracheae

The spiracular trachea has its origin from the main trunk at about the level of the anterior end of the body segment in which the spiracle is to develop in the last larval instar. In this intermediate instar the

spiracular tracheae have developed about one half of their final extent, ending as blind tubes in the body cavity. As development progresses they proceed in a ventro-latero-ectal direction, toward the destined position of the spiracle, midway between the intersegmental grooves.

Transverse connectives

The transverse connectives of this intermediate instar are similar in form to those of the first instar except that, whereas the latter had a constant number of nine connectives, in the former (Pl. LXVIII, Fig. 2 *tns*) the number has increased to eleven. This number remains constant throughout the rest of the larval stage of the insect.

Ganglionic and nerve-cord tracheae

Similarly, the ganglionic and nerve-cord tracheae are of the same form as those already described for the first instar. Furthermore, there are eleven pairs, a number that corresponds to the number of transverse connectives, whereas in the first instar the number of paired ganglionic tracheae corresponds to the number of transverse connectives present at that stage.

Caudal filaments

The tufts of caudal filaments present the same general appearance in this intermediate instar as they do in the first. The average number of filaments in each tuft is approximately the same. The length and the diameter of the filaments, however, have increased in proportion to the greater length of the larva itself. Associated with the caudal filaments, a new structure has made its appearance in the intermediate instar. This structure is here called the "caudal chamber" because of its position and nature. Its morphology will be discussed later under a separate heading. Tracheae of all other structures seen in the ventral view of the respiratory system are comparable to those for the first instar described above; consequently, no further description is needed.

Dorsal Aspect

The dorsal aspect of the respiratory system of the intermediate larval instar is essentially like that of the first instar in every respect except for the visceral tracheae and those advances in development already described in the discussion of the ventral aspect.

The visceral tracheae do not differ fundamentally in structure from those in the first instar. There is, however, an increase in the number of branches supplying the visceral organs (Pl. LXVIII, Fig. 1 vt_1-vt_{11}), which are larger and more advanced in development than they are in the first instar.

MORPHOLOGY OF LAST LARVAL INSTAR

In the last larval instar (Pl. LXIX; Pl. LXX, Fig. 1) the respiratory system is in every respect similar in structure to that of the intermediate instar, except that the spiracular tracheae are now completely developed and that the spiracles make their appearance. A detailed description of the spiracles and their tracheae will be given later under a separate heading.

MORPHOLOGY OF FILAMENTS AND CAUDAL CHAMBER

Caudal Filaments

As previously stated, the filaments are aggregated into three tufts. There appears to be no increase in their number as the larva develops, but there is an appreciable increase in size. Their length in the last instar varies from 464 to 608 μ . The diameter of each filament in this instar is about 6.2 μ at the proximal end and 2.7 μ at the tip. Likewise, the layer of chitin is relatively much thicker in the filaments of the last instar larvae. However, the number of tracheoles that supply each filament remains the same. Two tracheoles, characteristically twisted about each other, are in each filament of all instars.

Caudal Chamber

The histological structure of the wall of the caudal chamber is apparently similar to that of the filaments, with the exception of the chitinous layer, which is relatively thinner. The caudal chamber completely invests the main tracheal trunks and the intestine in that region; its wall lies close to the body wall. Branches from the main trunks supply the wall of the caudal chamber on its inner face. In the wall they break up into a network of tracheoles, which completely ramify the inner layers. Thus the caudal chamber wall furnishes a relatively large surface of comparatively thin tissue, through which diffusion of gases may readily take place.

At the posterior end, in the region of the caudal tufts, the chamber

wall is divided into three separate tubelike parts, each of which envelops the main tracheal trunks at their distal ends. Each of these parts, as well as the remainder of the caudal chamber wall, is capable of shortening, by forming a series of folds, when the caudal filaments are retracted into the body. The tissue that composes the wall is, therefore, fairly flexible owing to its reduced chitinization. This condition makes it possible for the caudal tufts to be extended and retracted with an ease that would not be possible if the wall of the caudal chamber were rigid.

Apparently, that rhythmic extension and retraction of the tufts which occurs under certain conditions is not due to muscles extending from the body wall to the wall of the caudal chamber, since thus far no muscles have been found that are in any way connected with the caudal chamber or with that part of each tracheal trunk which lies within the chamber. It does not seem likely that muscles operating the mechanism of the caudal tufts, if present, would be so minute as to escape detection. However, this subject requires further investigation before a definite statement can be made concerning the method of action of these caudal structures.

MORPHOLOGY OF SPIRACLES

Position

It has already been stated that the spiracles are not found until the larva attains its last instar. There are, in all, ten pairs of spiracles, two in the thorax and eight in the abdomen. Thoracic spiracles are located in the mesothorax and metathorax. Abdominal spiracles are located in the first eight segments. The position of the spiracles is a ventrolateral one. The "ears" of the spiracles protrude outside the body wall midway in the segment and on the ventral portion of the pleura, so that, if a larva is crawling on a wet surface, the apertures of the spiracles are in contact with that surface.

Structure

Each spiracle is surrounded by an outer rim (Pl. LXX, Fig. 2 *or*), which is more highly chitinized than the rest. The aperture of the spiracle is closed by two lightly chitinized membranes (Pl. LXX, Fig. 2 *mem*), which prevent the entrance of water into the tubes and probably act as diffusion membranes. These membranes are attached all along their outer edge to the periphery of the spiracular aperture.

Across the center of the aperture the membranes meet in a straight line parallel to the long axis of the body. These median edges are fused to each other, the straight line being, to all appearances, a suture marking their point of juncture. Under no circumstances do these membranes pull apart to form an opening which would communicate with the tracheal tubes, nor are they provided with muscles or levers which might serve to open and close them.

Entad from the aperture is a short vestibule, the wall of which is made up largely of cuticle. This vestibule leads into the spiracular trachea, where the chitinous lining is modified by the presence of taenidia. The spiracular trachea enters the main trunk at the position already described. Morphologically, the tracheal system of the last instar larva is an open one, except these membranes in the openings of the spiracles.

DIGESTIVE SYSTEM AND RELATION TO CAUDAL CHAMBER AND FILAMENTS

GASTRIC MILL

The mouth opens into a simple, thin-walled tube, which gradually grows broader as it reaches the posterior end of the prothorax. At this point two layers of short longitudinal bundles of muscle fibers are laid end to end, forming a curious structure that suggests a gastric mill. This gastric mill usually contains numerous diatoms, but occasionally rotifers, microcrustacea, and particles of marl also occur in it. Its structure is the same in all larval instars. Its size, however, increases proportionately with the size of the larva.

INTESTINE

From the gastric mill the intestine continues as a thin-walled tube, which gradually tapers as it approaches the anal aperture. Muscles and branches of the tracheal system serve to hold it at approximately the middle of the body.

ANAL APERTURE

Throughout the development of the larva no changes occur in the digestive system except for the relation between the anal aperture and the caudal chamber when the latter appears. It has been shown that in the first instar (Pl. LXVII, Figs. 1-2) the caudal filaments are

grouped in tufts about the posterior ends of the main tracheal trunks. The intestine and the anal aperture in this instar are not associated with the caudal filaments. At the extreme end of the last abdominal segment the sternum is provided with a shieldlike sclerite, which is hinged at its cephalic end and is free all the way to the tip of the abdomen, and is thus enabled to open and close that part of the abdomen when the tufts are extended and retracted. Therefore, in this instar the anal aperture opens to the outside independently of the caudal filaments when the sclerite is open. However, when in later instars the caudal chamber is developed, the tufts and the anal aperture become associated with it. The posterior end of the intestine becomes enveloped by the wall of the caudal chamber, and the anal aperture takes its position in the middorsal tuft, the filaments of which completely surround the opening. A peculiar phenomenon sometimes occurs in larvae that have the caudal chamber. If living larvae are dropped into concentrated sulphuric acid or some other extremely injurious liquid, they struggle violently and ultimately die. This struggle causes the intestine to break just above the place of attachment of the caudal chamber, and the lowermost part of the intestine becomes extraverted through the anal aperture. This brief description of the alimentary tract has been included in the discussion of the respiratory system because of the relationship between them in the older instars.

GENERAL DISCUSSION OF RESPIRATORY SYSTEM

It is seen from this study of *Stenelmis sulcatus* that the larval respiratory system is essentially a terrestrial one which has become secondarily modified for an aquatic habitat. There is, on the whole, no unusual specialization in the tracheal system. There are typically ten pairs of spiracles, a number which, according to MacGillivray (1923), represents the most primitive condition, at least in the higher forms, in which the tracheal system is fused into a connected whole and from which many specializations have developed that involve the loss of some or all of the spiracles. The caudal chamber appears to be a specialized structure but, to judge by its morphology, it does not seem to be respiratory in function in the same sense as is the respiratory chamber, described by Kuster (1933), which is found in *Stratiomyia* and *Odontomyia* larvae and into which the tracheal system opens by means of a pair of posterior spiracles. The caudal filaments are

true chitinous filaments supplied with tracheoles and are a direct continuation of the tracheal system. These filaments must not be confused with those hairlike structures at the terminal end of the abdomen in the larval forms of some other insects such as "*Stratiomys*" *chameleon*, which Henneguy (1904) and Berlese (1909) describe as "rigid, chitinous filaments," and which Wahl (1900) calls "bristles" when referring to similar structures in *Eristalis tenax* L., and which Dunavan (1929), working with *Eristalis arbustorum* L., calls "feather-like setae." In all these forms the structures are essentially hairlike, and those of stratiomyiad larvae have been adequately described by Kuster, who calls them "plumose hairs."

The terminology used in describing the tracheal system of *Stenelmis sulcatus* follows, so far as possible, that of Kennedy (1922) whenever homologous parts are being described and when the homology of the tracheae is obvious, which is true of the larger tubes. In designating some of the lesser tubes names have been adopted from the structures which the tracheae in question supply. This system has been resorted to because, up to the present time, Kennedy's work, already mentioned, still remains the only attempt to homologize the various parts of the tracheal system of insects. This is true in spite of the large amount of work that has been done on the respiratory system in the present century, to say nothing of the work that preceded 1900. To the investigators in this field one might here add several others merely to give the reader some idea of the wide diversity of the groups studied. Thus Miall and Hammond (1900) studied the morphology of the harlequin fly; MacGillivray (1903), the aquatic Chrysomelidae; Börner (1909), the Ephemerida; Böving (1910), the larvae of Donaciinae; Brocher (1911) and Alt (1912), Dytiscus; D'Orchymont (1913), the Hydrophilidae; and the list could be expanded to include nearly all the groups of insects. Therefore, the necessity for an extensive work on homology of the respiratory system is quite obviously an urgent one, and Kennedy's work, though it is splendid so far as it goes, is after all only a beginning.

SUMMARY

1. Both larvae and adults of *Stenelmis sulcatus* occur in marl concretions and are permanently submerged, never coming to the surface for air.

2. The larval tracheal system has fewer branches in the first instar than in all older larvae.

3. In the first larval instar neither spiracles nor spiracular tracheae are present.

4. The intermediate instar studied has spiracular tracheae, which are about half developed.

5. Last instar larvae have completely developed spiracular tracheae and ten pairs of spiracles. The spiracular apertures are permanently closed by weakly chitinized membranes.

6. Larvae of all instars possess three tufts of caudal filaments at the posterior end of the main tracheal trunks. These tufts are protrusible through the tip of the last abdominal segment.

7. Intermediate and last instar larvae possess a caudal chamber associated with the caudal filaments.

8. The tracheal system of all larval instars is a closed one.

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ABBREVIATIONS USED IN PLATES

- I-II — mesothoracic and metathoracic spiracles
 1-8 — abdominal spiracles
an — anus
at — antennal tracheae
bw — body wall
bwt — body-wall tracheae
cc — caudal chamber
cct — caudal-chamber tracheae
cw — chitinous wall of caudal filament
dbw — dorsal body-wall tracheae
e — "ear" of spiracle
et, ot — ocellar tracheae
gm — gastric mill
h — head
ht — head tracheae
int — intestine
l₁, l₂, l₃ — leg tracheae
lt — lateral tuft of caudal filaments
ltb — branch of main tracheal trunk supplying lateral tuft of filaments
m — "mouth" or aperture of spiracle
mdt — middorsal tuft of caudal filaments
mdbt — branch of main tracheal trunk supplying middorsal tuft of filaments
mem — membranes closing spiracular aperture
mes — mesothorax
met — metathorax
mtt — main tracheal trunk
or — strongly chitinized outer rim of spiracle
pro — prothorax
sp — spiracle
st — spiracular trachea
ste — spiracular trachea evagination
tc — transverse connectives
tns₁-tns₁₁ — ganglionic and nerve-cord tracheae
tr — tracheole
v — spiracular vestibule
vbw — ventral body-wall tracheae
vt₁-vt₁₁ — visceral tracheae supplying digestive system

EXPLANATION OF PLATE LXVII

FIG. 1. Ventral aspect of respiratory system of first instar larva

FIG. 2. Dorsal aspect of respiratory system and its relation to the digestive tract.
First instar larva. Actual number of caudal filaments more than twice the number represented

PLATE LXVII

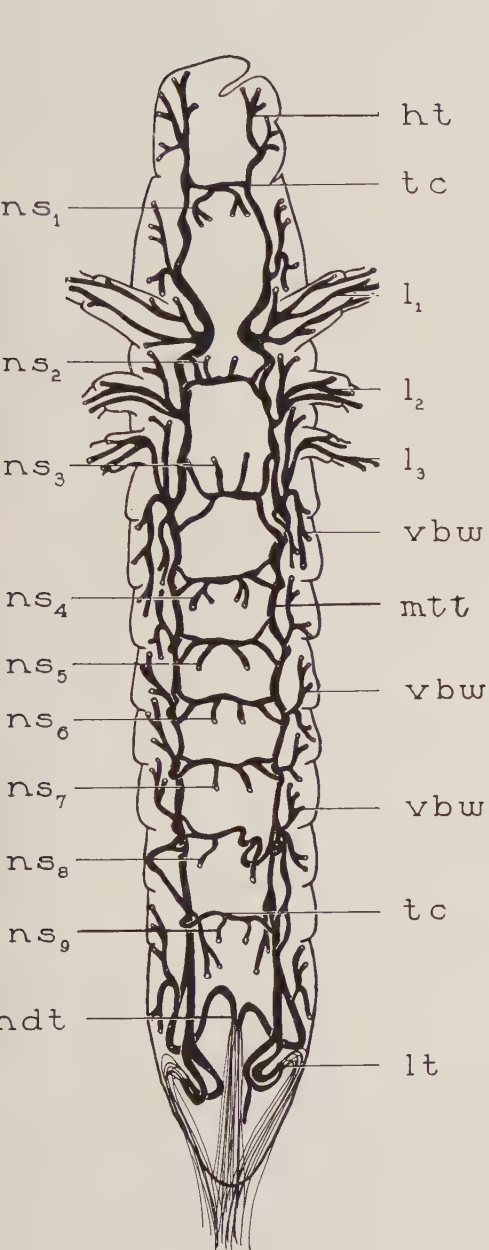


FIG. 1

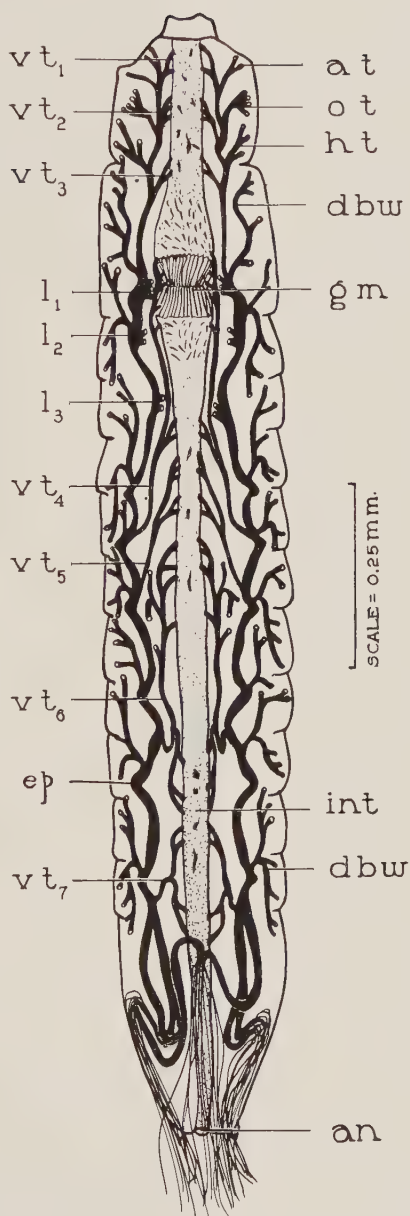


FIG. 2

EXPLANATION OF PLATE LXVIII

- FIG. 1. Dorsal aspect of respiratory system of intermediate instar larva. Caudal chamber and filaments not shown
- FIG. 2. Ventral aspect of respiratory system of intermediate larva, showing caudal chamber and continuation of main tracheal trunks into caudal filaments

Caudal filaments diagrammatically drawn; their number is greatly reduced in the figure

PLATE LXVIII

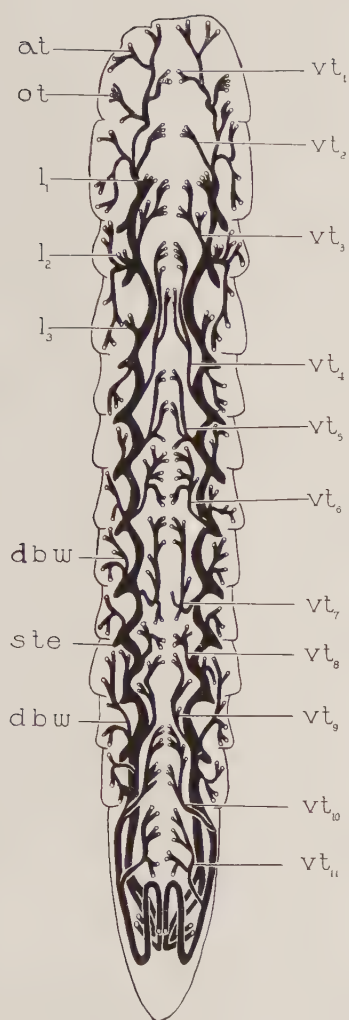


FIG. 1

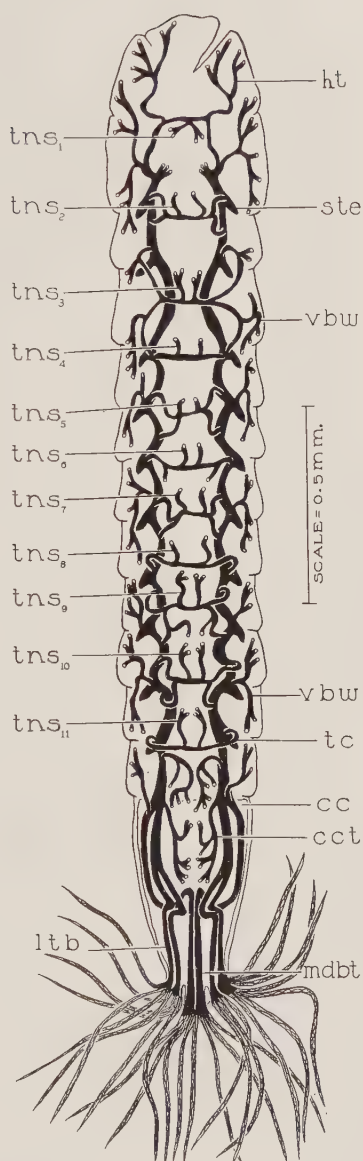


FIG. 2

EXPLANATION OF PLATE LXIX

- FIG. 1. Dorsal aspect of the respiratory system of last instar larva. Caudal chamber and caudal filaments not included in figure
- FIG. 2. Ventral aspect of the respiratory system of last instar larva. Caudal chamber and filaments not included in figure
- FIG. 3. Sagitto-lateral view of head and thorax of last instar larva, showing portion of one main tracheal trunk and tracheation of legs

PLATE LXIX

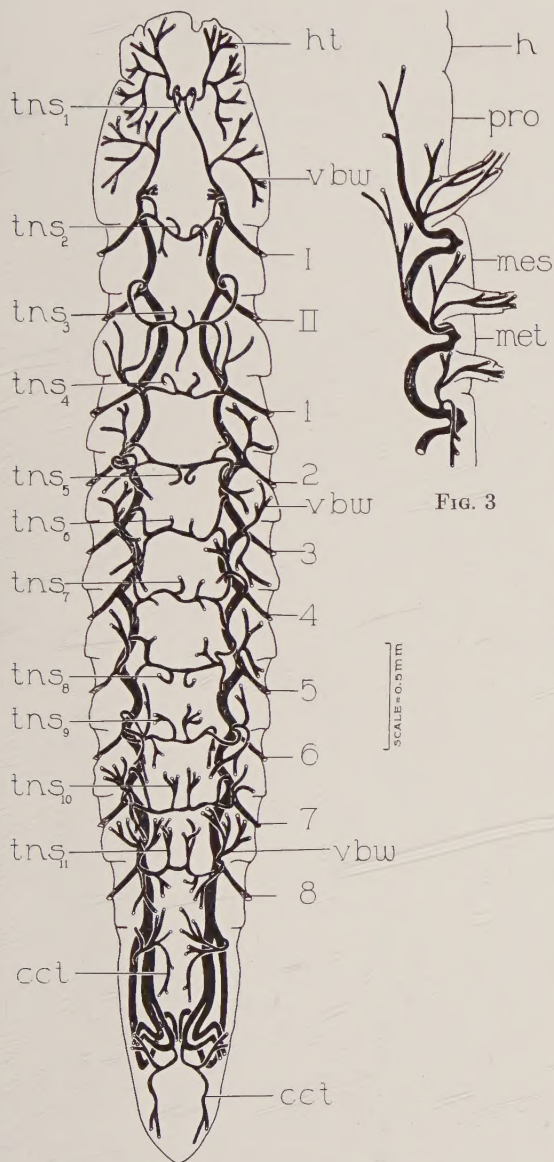


FIG. 1

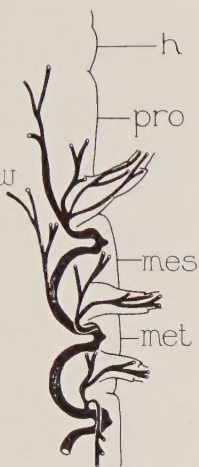


FIG. 3

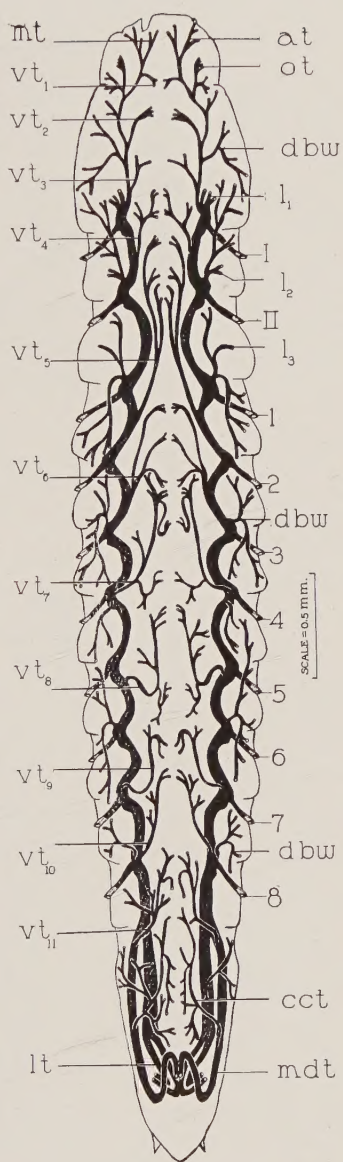


FIG. 2

EXPLANATION OF PLATE LXX

- FIG. 1. Diagram of caudal chamber and caudal filaments of last instar larva and their relation to main tracheal trunks. Filaments represented less than one half actual number
- FIG. 2. A. Side view of abdominal spiracle, greatly enlarged, showing vestibule and "ear"
B. Face view of spiracle. Aperture or "mouth" of spiracle closed by two membranes fused in middle and attached along periphery of spiracular aperture
- FIG. 3. Abdominal spiracle, showing connection with tracheal system
- FIG. 4. A. Longitudinal view of caudal filament, greatly enlarged
B. Transverse view of the same filament

PLATE LXX

